Reflectance from a sinusoidal bottom and discrimination of water types with hyperspectral data

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LONG-TERM GOALS

The availability of hyperspectral imagery raises the possibility of expanding the range and specificity of components that might be identified, and of delineating simple vertical structure. This is particularly important in the coastal zone where terrigenous sources of chromophoric dissolved organic material (CDOM) and inorganic particulates seriously complicate the retrieval of information from remote signals. Our long-term goal is the development of a set of spectral analysis tools that fully exploit the information content in hyperspectral image data, particularly as it applies to remote sensing of ocean color and the extraction of bathymetry, water quality and bottom type information.

OBJECTIVES

This work addresses two issues that affect hyperspectral data analysis: the effects of morphology on bottom reflectance and the inversion of water-leaving radiance spectra to infer information about the optical properties of the water.

The objective for the first task is to develop a model that portrays the reflectance of an irregular bottom. Locally – when the local roughness scale is much greater than the wavelength, but much smaller than the instrument field of view (FOV) – we assume that the reflectance is Lambertian. The larger-scale roughness (on the order of the instrument FOV) is characterized using a sine wave of varying amplitude and wavelength. The assumption of local Lambertian reflectance does not imply that the overall reflectance is Lambertian since in the far-field, inhomogeneities, texture, variations in slope and large-scale roughness become important in determining the reflectance distribution. The fundamental question is the degree to which bottom morphology will alter the magnitude and spectral quality of the light reflected from the bottom.

The second objective is to make better use of the full spectral range available in hyperspectral data to relate the water leaving radiance to the water IOPs. In particular, we consider the applicability of a simple reflectance model for characterizing the spectral reflectance and compare spectral measured and modeled spectral reflectance and the spectral derivatives for insights into the design of more effective hyperspectral ocean color algorithms.

APPROACH

1) By using an analytical model to describe reflectance from a rough surface, we expect to better understand the details of the reflectance process. While there is a limit to the complexity that can be treated analytically, it is possible to include most of the critical physical properties that affect

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reflectance from a rough surface. The model is structured to be capable of including higher order reflectance, but computations are limited to 2^{nd} order reflectance. The model is also designed to include shadowing and obscuration effects.

2) The premise of the second task is that, since airborne surveys can now provide the spectral water-leaving radiance with reasonable precision, spectral analysis of this signal may provide detailed information about the water and its constituents.

The key to identifying different water types lies in the relationship between the water irradiance reflectance, R_w, and water IOPs. The standard analytic model used for this purpose was originally derived by Gordon et al. (1975) and further developed in Gordon et al. (1988). The relationship most commonly used is of the form:

$$R_w \propto [b_b/(a + b_b)] \qquad (1)$$

where a is the absorption coefficient and b_b is the backscattering coefficient. Equation (1) has been the basis for most of the semi-analytic algorithms designed to detect the presence and amount of chlorophyll in the water (O'Reilly et al., 1998; Reynolds et al., 2001). We are exploiting the utility of derivative analysis. Our hypothesis is that it will be possible to relate the local spectral shape to changes in the water IOPs.

Taking the derivative of Equation (1) with respect to wavelength, λ, yields:

$$\frac{dR}{d\lambda} \propto \frac{1}{(a+b_b)^2}\left\{ a\frac{db_b}{d\lambda} - b_b\frac{da}{d\lambda}\right\} \qquad (2)$$

Equation (2) implies that the spectral changes in reflectance should be sharply different for turbid coastal waters as compared to clear ocean waters. In clear ocean waters, $a >> b_b$ and $db_b/d\lambda$ will be dominated by molecular scattering making the first term dominant except in the vicinity of a strong absorption peak (e.g., chlorophyll). In contrast, in a strongly scattering medium, the absorption coefficient will still be greater than b_b, but scattering will be dominated by particle scattering in which case one might expect little spectral variation in the scattering ($db_b/d\lambda \approx 0$). In that case, the second term will tend to dominate. This suggests, paradoxically, that the shape of the absorption spectrum can dominate the spectral change in reflectance for strongly scattering waters.

In summary, the approach is to examine this and other derivative relationships (higher order derivatives, ratios of derivatives, etc.) for insights into the design of more effective hyperspectral ocean color algorithms. The relationships will be tested using HYDROLIGHT (Mobley, 1995) to predict water-leaving radiance for ranges of water properties, supplemented by realistic IOPs computed using the Ocean Optical Plankton Simulator (OOPS) (Kim and Philpot, 2000). The relationships will be verified using existing field observations wherever possible.

WORK COMPLETED

1) An analytical model describing 1^{st} and 2^{nd} order reflections for a sinusoidal bottom with locally Lambertian reflectance has been completed and the results compared to measurements and the predictions of stochastic models for similar conditions.

2) Derivative formulae have been derived based on the reflectance function in Equation (1). Reflectance spectra and the appropriate spectral derivatives have been computed from measured IOPs and compared to reflectance spectra (AOPs) measured directly at the same times and locations as the IOPs.

3) Historical data have been collected from two study sites: 1) the Atlantic Ocean off the coast of New Jersey, and 2) the Gulf Coast of Florida. Characteristic values for the range of pigments, CDOM, and particulates have been collected from the literature and available databases (e.g., the Worldwide Ocean Optics Database.

RESULTS

The effect of bottom morphology on reflectance

The case modeled is that of a sandy, sinusoidal bottom. For simplicity, we allow the incidence angle to vary from +50° to -50°, but consider only a nadir-viewing detector for all cases. The maximum reflectance occurs for the sun at zenith and drops off rapidly as the sun angle increases (*Figure 1*). For a flat bottom there are virtually no 2nd order reflections. As the amplitude of the bottom waveform increases the reflectance remains symmetric with the illumination angle, and the amplitude of the first order reflectance decreases. The decrease is noticeable even for relatively modest amplitudes and the reflectance is down by almost 20% for the most extreme amplitude considered. However the contribution from the 2nd order reflections increases with the amplitude of the bottom waveform. This contribution is negligible for small amplitude waves but increases to more than 10% of the total for the roughest waveform considered. Thus, the second order reflectance mitigates the change in the overall reflectance as the waveform amplitude increases.

While the overall total reflectance is dominated by the magnitude of the first order reflections, the second order reflections make a significant contribution when the surface is very rough. For still more extreme waveforms the second order reflectance would even be more significant since second order reflectance would be the only radiation received from the shadowed and obscured regions of the waveform. Note that, for the wave amplitudes and illumination angles considered here, shadowing and obscuration effects are negligible. When these factors become more important the contribution of second order reflectance should increase substantially.

As higher order reflectance becomes important, absorption by the bottom will be enhanced. In the cases tested, however, absorption by the bottom did little to change the overall spectral reflectance. However, the increase in absorption by the water (due to the increase in the optical path through the water) was substantial, especially in the red.

Shadowing of points along the bottom occur when the incidence angle is greater than the maximum slope of the waveform – in this case for waveforms with amplitude-to-length ratios above 25%. Similarly, obscured points are those that do not have direct paths to the detector, but which have not been considered in this simplifying case of nadir viewing. The drop in first order reflectance is expected to be greater for when shadowing occurs than that for obscuration. On the other hand, there is much greater contribution from second order reflections to total reflectance in regions that are shadowed. It is interesting to note though that this does not affect the symmetry of the total reflectance of a single waveform as the illumination angle changes.

IMPACT/APPLICATIONS

Bottom reflection: Reflectance from a rough surface is dominated by the magnitude of the first order reflections. However, as the roughness increases, higher-order reflections begin to make a significant contribution. For the wave amplitudes and illumination angles considered here, shadowing and obscuration effects are negligible. When these factors become more important the contribution of second order reflectance should increase substantially. Changes in the spectral character of reflectance are not as responsive to changes in roughness. Absorption by water, due to the increased optical path in water, dominates the change in the spectral reflectance. Increased absorption by the bottom due to multiple reflections, does not appear to be significant for the modeled cases.

Spectral reflectance: Reflectance spectra computed from IOPs using Equation (1) differ both in magnitude and spectral detail from those measured directly at the same time and location as the IOP measurements. Barring errors in the measurements that we have not found, this calls into question the utility of Equation 1 (or the power law version in Gordon's original papers) when applied to coastal waters.

TRANSITIONS
None

RELATED PROJECTS

The bottom reflectance portion of this project is coordinated with the work of Drs. Zaneveld and Boss, who approach the same problem using ray tracing and Monte Carlo models. The intent is to use each model where it is strongest, crosschecking the models where feasible and developing a consistent description of the effect of morphology on the spectral and directional reflectance of the sea bottom.

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Clavano, W.R. and W. D Philpot (2002) *Reflection from a sinusoidal surface.* Ocean Optics XVI, 18-22 November, 2002, Santa Fe, NM.

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